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EFFECTS OF DIFFERENT LIGHT QUALITY ON POST-HARVEST TOMATO QUALITY

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Abstract

This study investigated how various light qualities impact the levels of lycopene, soluble sugars, total phenolic, soluble solids, and soluble protein in post-harvest tomatoes (*Solanum lycopersicum* L.) to identify an appropriate form of artificial lighting. The test subjects included green tomatoes weighing 50g, 60g, and 70g. A single factor randomized block design was employed, where the cleaned and dried tomato fruits were subjected to five different light sources: fluorescent lamps (the control, CK), purple light (PL), blue plus red (BR), blue (B) and red (R) derived from rare earth plant light sources. The findings revealed that the content of lycopene and soluble protein in the tomatoes increased progressively with longer exposure times to the various light conditions. Specifically, tomatoes exposed to BR light exhibited the highest lycopene content, followed closely by those under R and B lights, while CK had the lowest. In terms of soluble protein, higher levels were noted in the BR and R treatments, with B and PL displaying moderate levels, and CK yielding the least. The soluble sugar levels were also highest under BR and R lights, followed by B and PL, with CK again being lower. For soluble solids, the highest content was found in tomatoes under BR conditions, with B and CK next, and PL showing the least. The total phenolic content peaked under BR and B treatments, followed by R, while CK and PL had reduced levels. Overall, utilizing BR light for post-harvest tomato irradiation appears to significantly enhance the quality of the physiological characteristics of the fruit. This research lays the groundwork for regulating the quality of post-harvest fruit and vegetables in relation to the control of the light environment, offering both theoretical insights and practical support.

Key words: Light quality; Post-harvest; *Solanum lycopersicum*; Lycopene content.

Introduction

Light serves as a fundamental physical factor in determining the growth and development of plants, playing a particularly vital role in the photosynthesis process. The quality and wavelength of light are crucial variables that can greatly influence the synthesis of both primary metabolites, such as proteins and carbohydrates, and secondary metabolites, which include flavonoids and anthocyanins. These bioactive compounds are instrumental in imparting distinct characteristics to various cultivated horticultural and agricultural species, affecting attributes such as taste, appearance, aroma, and overall quality (Livadariu *et al*., 2023). Nevertheless, it is essential to remember that not all parts of the light spectrum have a positive effect on plant growth. Plants predominantly absorb radiation that resides within the visible spectrum. They employ at least five distinct types of sensory photoreceptors, each with a specific affinity for detecting different regions of the electromagnetic spectrum. To illustrate, cryptochromes (CRYs) and phototropins (PHOTs) serve as blue light receptors, absorbing light at wavelengths spanning from 390 to 500 nm. In land plants, phytochromes (PHYs) exhibit a dynamic equilibrium that is influenced by the ratio of red (660 nm) to far-red (730 nm) light, a phenomenon first described by Möglichkeit *et al*., (2010). Jiao *et al*., (2007) reveal that these photoreceptors have the function of capturing and processing photonic information, subsequently translating it into alterations in gene expression that regulate the development and differentiation of plants.

Tomatoes are categorized as climacteric fruits, meaning they continue to ripen even after being harvested. During the ripening phase, the green pigment known as chlorophyll undergoes degradation, while the synthesis of carotenoids takes place. Lycopene and β-carotene stand out among these carotenoids, serving as the primary contributors to the vibrant pigmentation of ripe tomato pericarp, which gives rise to the characteristic deep red and orange hues, respectively (Liu *et al*., 2009). The presence of these carotenoids plays a substantial role in influencing the perceived quality of fresh tomatoes. For consumers, two of the most significant quality attributes are texture and color, as they have a direct impact on the marketability of the fruit. Additionally, the carotenoid content in tomatoes is vital not only for the visual appeal it provides but also for its recognised health benefits, which adds value to the fruit for consumers.

At present, a number of studies have been conducted to investigate the influence of light quality regulation on the quality of plants and fruits (Liu *et al*., 2009; Li *et al*., 2010; 2017; Zhang *et al*., 2021; Samkumar *et al*., 2021; Wang *et al*., 2022; Li *et al*., 2023; 2024). It should be noted, however, that the effects of light quality also vary depending on the specific crop species or varieties under consideration. Prior research has demonstrated that the accumulation of lycopene in tomato fruits is enhanced by red light, whereas far-red light has the opposite effect. The application of red light has been demonstrated to enhance the accumulation of lycopene in tomato fruits by stimulating the activity of phytochrome (PHY). This, in turn, inhibits the accumulation of phytochrome interacting factor (PIF) proteins, thereby facilitating an increase in phytoene synthase (PSY) expression (Leivar & Monte, 2014). Although many studies have examined how light affects lycopene accumulation, the role of blue light in determining lycopene levels in undetached tomatoes is not well understood. Importantly, enhanced levels of lycopene in tomatoes have been linked to the overexpression of the blue

light receptor CYR1a (Liu *et al*., 2017). Loughrin & Kasperbauer (2001) demonstrated that the size of basil leaves, as well as their aroma and concentrations of soluble phenolics and antioxidants, were influenced by the quality of light. Bantis *et al*., (2016) further demonstrated that varying light treatments influenced both the growth traits and the overall phenolic content of basil cultivars. The non-biological environment, especially light, is essential in the fruit ripening process during both the pre-harvest and post-harvest phases of the tomato supply chain since it can greatly influence the metabolomic profiles of the fruits (Ntagkas, *et al*., 2020). Moreover, little is generally recognized about the effect of light quality of different rare earth light sources on postharvest tomato quality. The present experiment employed a range of light sources to determine the most suitable conditions for irradiating post-harvest tomatoes. Specifically, fluorescent lamps (CK) were utilized as the control light source, while the study also examined the effects of purple light (PL), a combination of blue plus red light (BR), as well as blue light (B) and red light (R) independently. The principal objective of the research was to examine the effects of these diverse light sources influenced specific quality characteristics in post-harvest tomatoes. By analyzing the effects of various light spectrums on these tomatoes, the study sought to identify optimal light sources and corresponding control technologies for light irradiation. Ultimately, the findings of this research are intended to provide a robust theoretical foundation and technical guidance for the selection and application of appropriate light sources in the post-harvest treatment of tomatoes, thereby enhancing their quality during storage and distribution.

Material and Methods

Plant materials: This study was undertaken in a greenhouse setting at the Suzhou Polytechnic Institute of Agriculture from November 2023 to Jun 2024. The tomato variety 'Xinhong 18' (*Solanum lycopersicum* L.) fruits at the green-ripe stage, exhibiting consistent maturity and free from pests or diseases, were selected based on individual fruit weights of 50, 60, and 70 g. These fruits were promptly transported to the laboratory after harvest. Initially, the tomatoes were rinsed in running water for 15 to 30 minutes, followed by soaking in distilled water for 2 to 3 hours, and subsequently dried with a fan for later use.

Light treatments: In accordance with the principle of maintaining consistent light intensity, a single-factor randomized block design was employed. Tomatoes of varying single fruit weights were randomly positioned under different light sources: fluorescent lamps (CK, T5-28W, Philips Lighting Industries Co., Ltd., Yangzhou, China), purple light (PL), a combination of blue plus red (BR), blue (B), and red (R) (40W, Shanghai Heming Lighting Appliance Co., Ltd., Shanghai, China). The spectral distributions for each light source are presented in Table 1. The intensity of the light source was consistently kept at the same level of 30 μmol·m^{-2}s^{-1}, with a photoperiod of 12 hours per day. The environmental conditions were controlled to maintain a temperature range of 14～16 °C and a relative humidity of 85%～90%. Each treatment included 60 tomatoes, and during the irradiation process, the fruits were rotated daily to ensure uniform exposure to the light.

Table 1. Spectral distribution of lights.

Light treatment	Light spectral distribution	Peak value λp (nm)	Half wave width Δλ (nm)	Light intensity (μmol m^{-2} s^{-1})
CK	Fluorescent lamp	380~760	—	30
PL	Purple	390	5	30
BR	Blue/red (1:1)	660/460	5	30
B	Blue	460	5	30
R	Red	660	5	30

Measurements: Sampling was carried out for measurement on the 7th, 14th, and 21st days after irradiation, respectively. The lycopene content was calculated using the methodology outlined by Toor & Savage (2005). A subsample of 0.5 g was obtained and dissolved in 20 ml of an extraction solution comprising n-hexane, acetone, and ethanol in a 2:1:1 ratio. The solution was agitated for one hour in the absence of light, following which it was subjected to centrifugation at 10,000 rpm and 4°C for ten minutes. A blank was prepared using n-hexane, and the absorbance was measured at 472 nm. The calculated extinction coefficient (E%) was found to be 3450, and the results are presented as milligrams of lycopene per 100 grams of fresh weight (FW). The overall sugar content was derived through the implementation of a modified methodology, adapted from the techniques originally proposed by Martin *et al*., (2000). In the initial stage of the process, approximately 0.5 grams of the leaves were finely ground in a mortar with liquid nitrogen. Subsequently, 1 ml of 80% ethanol was combined with the mixture, which was then passed through a filter paper. The residues were rinsed with 70% ethanol and passed through a filter once more. The subsequent solutions were combined, and 3ml of sterile distilled water was added. Centrifugation at 12,000 rpm for 15 minutes resulted in the collection of 1 ml of the supernatant. The quantification of soluble sugar content was conducted using the sulfuric acid anthrone method, with absorbance measurements taken at 620 nm. Soluble solids were determined by a handheld refractometer. The method described by Toor & Savage (2005) was used to analyse the total phenolic content. Prepare a series of gallic acid standard solutions (0, 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 ml) with a solution of 100 μg/ml was prepared in a 10 ml volumetric flask. A volume of 1 ml of Folin-Phenol should be added, and the solution should be thoroughly shaken and left to stand for a period of 3～4 minutes. Subsequently, 3 ml of a 7.5% Na_2CO_3 solution should be added, and the volume should be adjusted to 10 ml with distilled water. The solution should be shaken

thoroughly and incubated at room temperature in the dark for a period of two hours. The absorbance at 765 nm should be measured and plotted on a standard curve, with the absorbance on the y-axis and the concentration on the x-axis. The sample should be weighed in a quantity of 3 g, and then 18 ml of a 40% ethanol solution should be added. The mixture should then be ground and extracted, after which it should be placed in a water bath at 60°C for one hour. Subsequently, the sample should be subjected to centrifugation at 10,000 rpm and 4°C for a period of 15 minutes. The resulting supernatant constitutes the sample solution. The supernatant should be accurately pipetted to a volume of 1 ml, and the subsequent procedure should be followed in accordance with that described for the standard curve in order to measure the absorbance. The results are expressed in milligrams of gallic acid equivalent per 100 grams of fresh fruits and vegetables, denoted as mg/100 grams of fresh weight (FW). The assessment of soluble protein utilized the Coomassie Brilliant Blue method (Li *et al*., 2024). A sample of 0.2 g (fresh weight, W) was extracted from the leaves of fifteen seedlings, with the objective of ensuring uniformity in position for each treatment. Subsequently, the leaves were pulverized in a mortar with liquid nitrogen, after which 5ml (V1) of potassium phosphate buffer (PBS) at a concentration of 0.067 mol/l was added, and the mixture was filtered using filter paper. The subsequent step involved centrifuging the extract at 12,000 rpm for 10 minutes, with the objective of separating the supernatants. The protein solution was prepared by combining 1 ml (V2) of the extract with 5 ml of Coomassie Brilliant Blue G-250 dye. The optical density was determined using a UV-1200 spectrophotometer (Jin Peng Inc., China) at a wavelength of 595 nm. A calibration curve was constructed by adding varying quantities of 100 μg/l bovine serum albumin (0, 0.2, 0.4, 0.6, 0.8, and 1 ml) to six calibrated flasks, with the addition of deionized water to achieve a final volume of 1 ml. The value of the optical density was re-assessed at 595 nm (ρ). The concentration of soluble protein was determined using the following formula: The concentration of soluble protein (mg/g) is calculated using the following formula: ρ V1 / (W V2)

Statistical analyses: Statistical analyses were performed using SPSS version 22.0. Data were analyzed using analysis of variance with Tukey's multiple comparison test ($p<0.05$) employed to identify any significant differences. The measurements were performed on three occasions.

Results

The changes in lycopene content in post-harvest tomato fruits: The lycopene content in tomato fruits with different weights exhibited a notable increase as the duration of light treatment was extended (Fig. 1). For tomatoes weighing 50 g, the highest levels of lycopene were achieved under a blue plus red light combination (BR). After a period of 7 days, the lycopene content showed a remarkable increase of 101.52% when compared to the fluorescent lamp control (CK), with statistical significance indicated ($p<0.05$). Interestingly, treatments involving blue (B), red (R), and purple light (PL) exhibited no significant differences among themselves, while CK displayed the lowest lycopene concentration. At the 14 and 21day marks, the lycopene content under the BR treatment continued to rise significantly, reaching increases of 113.83% and 126.85%, respectively, compared to CK. The other treatments, R, B, and PL, followed in this order of lycopene content, consistently showing higher levels than CK, which remained the least effective. Similarly, for tomatoes with a weight of 60 g, the trend observed at 7 days indicated that the highest lycopene content was again found under the BR treatment. This was followed by those subjected to blue, red, and purple light treatments, all of which significantly exceeded the CK level, although no significant differences were found among the three treatments. This pattern persisted at the 14day and 21day intervals, with BR continuously yielding the highest lycopene content, followed in succession by B, R, and PL, which all demonstrated significantly higher levels than CK. By the 21day observation, BR once again showed the highest content, with B and R treatments falling closely behind, though no significant differences were observed between them. PL ranked next, with CK remaining the lowest. For tomatoes with a weight of 70 g, the results at 7 days mirrored those of the lighter tomatoes, with the BR treatment yielding the highest lycopene content. This was again followed by the B, PL, and R treatments, all of which significantly surpassed CK. At 14 days, the BR treatment continued to exhibit the highest levels of lycopene, followed by B, R, and PL, consistently maintaining CK at the lowest level. Conclusively, at the 21day mark, BR still represented the treatment with the highest lycopene content, with subsequent contents ranked as B, R, and PL, which did not show significant differences among them, while CK remained the lowest throughout the experiment. The results showed that BR treatment can increase the lycopene content in tomatoes with different single fruit weights. The findings indicated that the treatment with BR can enhance the lycopene levels in tomatoes of varying individual fruit weights.

The changes in soluble sugar content in post-harvest tomato fruits: The experiment revealed a clear trend in the soluble sugar in tomato fruits of different weights in response to prolonged exposure to various light treatments (Fig. 2). Specifically, for the 50 g tomatoes, the soluble sugar levels were observed to be the highest after 7 days of treatment under blue plus red (BR), purple light (PL), and blue (B) conditions. Notably, the analysis revealed no statistically noteworthy discrepancy in the sugar content between the red (R) and control (CK) treatments, at this time, indicating that the specific light treatments were more effective than the R and CK conditions. As the treatment period extended to 14 days, the soluble sugar content reached its peak under BR and R treatments, with B and PL treatments also showing significantly higher sugar contents in comparison to CK, which consistently exhibited the lowest levels. By the end of the 21day period, the trend continued with BR treatment once again showing the highest soluble sugar content, subsequently, BR treatments exhibited considerably elevated levels in comparison to the control group. The CK and PL groups, on the other hand,

remained at minimal sugar levels, highlighting the advantages of specific light conditions in enhancing sugar accumulation in tomato fruits. For the 60g tomatoes, the results mirrored those of the 50g fruits. The BR treatment displayed the highest soluble sugar content at 7 days, with B, R, and PL treatments following in terms of sugar levels, while CK was distinctly lower. Again, after 14 days, the BR treatment maintained its lead, and at the end of the 21day observation, both BR and R treatments resulted in the highest soluble sugar contents, with B and PL lower yet still above CK. In the case of the 70g tomatoes, it was initially observed that the soluble sugar content remained consistent across all light treatments after 7 days. However, by 14 days, the R, BR, and B treatments emerged with higher sugar contents, while PL and CK had lower readings. This pattern persisted through the 21day period, wherein BR and R treatments demonstrated the highest soluble sugar concentrations, followed by B and PL, with CK remaining at the lowest. Collectively, these findings indicate that light treatments, especially BR and R, play a crucial role in significantly enhancing the soluble sugar content of tomato fruits was found to be consistent regardless of their weight categories.

The change of soluble solid in post-harvest tomato fruits: The aim of this study is to analyze the soluble solid in tomato fruits of varying weights during light treatment revealed that there is a gradual increase in this content as exposure time lengthens, as illustrated in Fig. 3. Specifically, for the 50 g weight category, after a duration of 7 days, the highest soluble solid content was observed in the fruits subjected to the blue plus red (BR) light treatment. This treatment resulted in a remarkable increase of 23.95% when compared to the control group (CK). Following the BR treatment, the fruits subjected to the blue (B) light treatment demonstrated the second-highest concentration of soluble solids. In contrast, the treatments involving red (R) and purple light (PL) did not show any significant differences amongst themselves, and the twos exhibited the lowest levels of soluble solids in comparison to the control. Continuing the examination after 14 days, it was again observed that BR treatment led to the highest soluble solid content among the groups. The treatments with red and purple light were both significantly higher than the control, whereas the control and blue treatments demonstrated the lowest levels of soluble solids. By the time the observation reached 21 days, the trend persisted, with BR treatment recording the highest results in soluble solid content, followed closely by the R, B, and PL treatments, all of which were markedly elevated in comparison to the control, with the control remaining at the lowest levels. Turning to the 60 g weight category, after 7 days, the B treatment showed the highest soluble solid content, followed closely by BR, PL, and the control, with the R treatment yielding the least. On day 14, once again, the BR treatment emerged on top for soluble solids, with B, R, and the control following behind, while PL was noted to have the lowest levels. By 21 days, BR maintained its position as yielding the highest soluble solid content, trailed by the B and PL treatments, while the control and R treatments were at the bottom of the results. In the case of the 70 g weight category, the BR treatment consistently produced the highest soluble solid content, overshadowing B and the control treatments, with PL yielding significantly lower levels. Collectively, these findings underscore the concluding observation that BR treatment performs a substantial function in the context of enhancing the soluble solid content in tomato fruits across various weight categories.

The change of total phenol content in post-harvest tomato fruits: The investigation into the total phenol in tomato fruits of various weights subjected to light treatment demonstrated a consistent upward trend in phenol levels as the duration of treatment increased, as illustrated in Fig. 4. At the 7day mark, tomato fruits weighing 50 g displayed a notably higher total phenol content under blue plus red (BR), blue (B), and red (R) light treatments. In contrast, the phenol levels in the fruits exposed to the natural light (PL) and control group (CK) did not show significant variations in comparison to one another, with a statistical significance of $p<0.05$. Moving to the 14day observation, the total phenol content reached its peak under the BR treatment, followed closely by the other two light treatments, B and R. The PL treatment exhibited a lower total phenol content than these treatments, while CK recorded the least number of phenols. By the end of the 21day treatment period, BR continued to demonstrate the highest total phenol levels, closely followed by B, and both PL and R treatments also yielded significantly higher phenol contents compared to the CK, which remained the lowest. For the 60g tomato fruits assessed at the 7day interval, the highest recorded total phenol content emerged from the BR and B treatments, with R and CK trailing behind, while PL maintained the lowest levels. Upon reaching 14 days, the trend continued with BR yielding the highest total phenol content once more, subsequently, B was observed to be significantly higher, while CK and R exhibited notable decreases, and PL retained its position as the treatment with the least phenol content. By day 21, the BR treatment still dominated with the highest total phenol levels, succeeded by B and R, while CK remained the lowest throughout this period. In the case of 70 g tomato fruits evaluated at day 7, the results indicated no significant differences in total phenol content across the various light treatments. However, by day 14, total phenol content was notably elevated under the R, BR, and B treatments, whereas both PL and CK resulted in lower total phenolic values. By the end of the 21day duration, the highest total phenol content was again registered under BR and R treatments, followed by B and PL, with CK maintaining the lowest levels. These findings strongly suggest that the application of BR and B treatments substantially boosts the total phenol of tomato fruits, highlighting the potential for enhancing the nutritional value of tomatoes through specific light exposure strategies.

The changes in soluble protein in post-harvest tomato fruits: The soluble protein content in tomato fruits of various weights subjected to light treatment demonstrated a gradual increase correlated with the length of treatment duration, as illustrated in Fig. 5. At the 7day mark, 50 g tomato fruits did not exhibit any significant differences in soluble protein levels across the different light treatments. However, by the 14day observation, the soluble protein content reached its zenith under BR and R lights, which represented increases of 53.67% and 54.29%,

respectively, when compared to the control group (CK). Following closely were the blue (B) and purple light (PL) treatments, both of which also showed significant enhancements over the CK group, which had the least soluble protein content. At the 21day time point, the BR treatment once again produced the highest levels of soluble protein, with R, B, and PL treatments also showing significantly elevated protein content compared to the CK, which continued to record the lowest measures. For the 60g tomato fruits evaluated at 7days, both BR and R treatments yielded the highest soluble protein levels, while B and PL treatments likewise demonstrated significant increases over CK. By the 14day assessment, BR and R treatments maintained their positions at the top of soluble protein content, while no notable difference was observed between PL and CK treatments. At the 21day mark, the BR treatment led once more in soluble protein levels, followed closely by B, R, and PL treatments, all of which significantly surpassed the CK, which again remained the lowest. In the case of 70g tomato fruits, the BR treatment produced the highest soluble protein content at the 7day point, trailed by PL, with R exhibiting the lowest values. Consistently, at the 14 and 21day evaluations, BR treatment sustained the highest soluble protein content, followed by PL, R, and B treatments, while CK continued to be the lowest. Overall, these findings indicate that both BR and R light treatments substantially boost the soluble protein of tomato fruits, reinforcing their significance in enhancing nutritional value during cultivation.

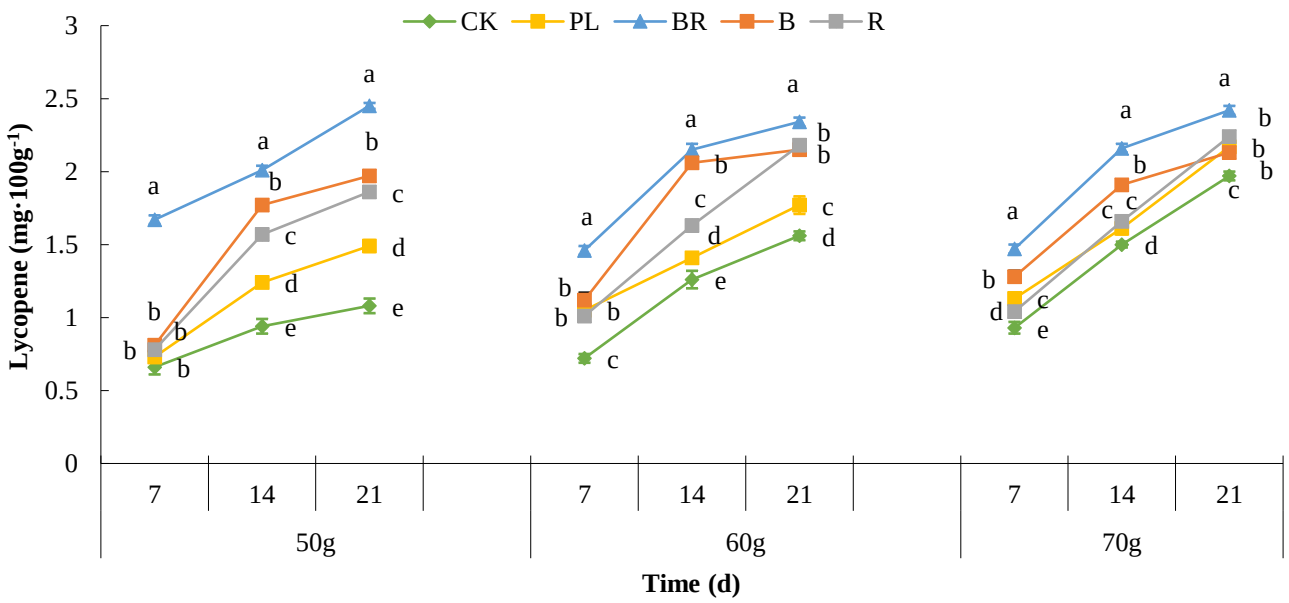

Fig. 1. Changes in lycopene in tomato fruits.
Note: CK: Fluorescent lamp; PL: 100% purple light; BR: 50% blue light plus 50% red light; B: 100% blue light; R:100% red light. The values presented are the mean ± standard deviation. The presence of different letters within a given column indicates the existence of statistically significant differences at the 0.05 level, as determined by Tukey's test (n=3). The same is true of the subsequent data set.

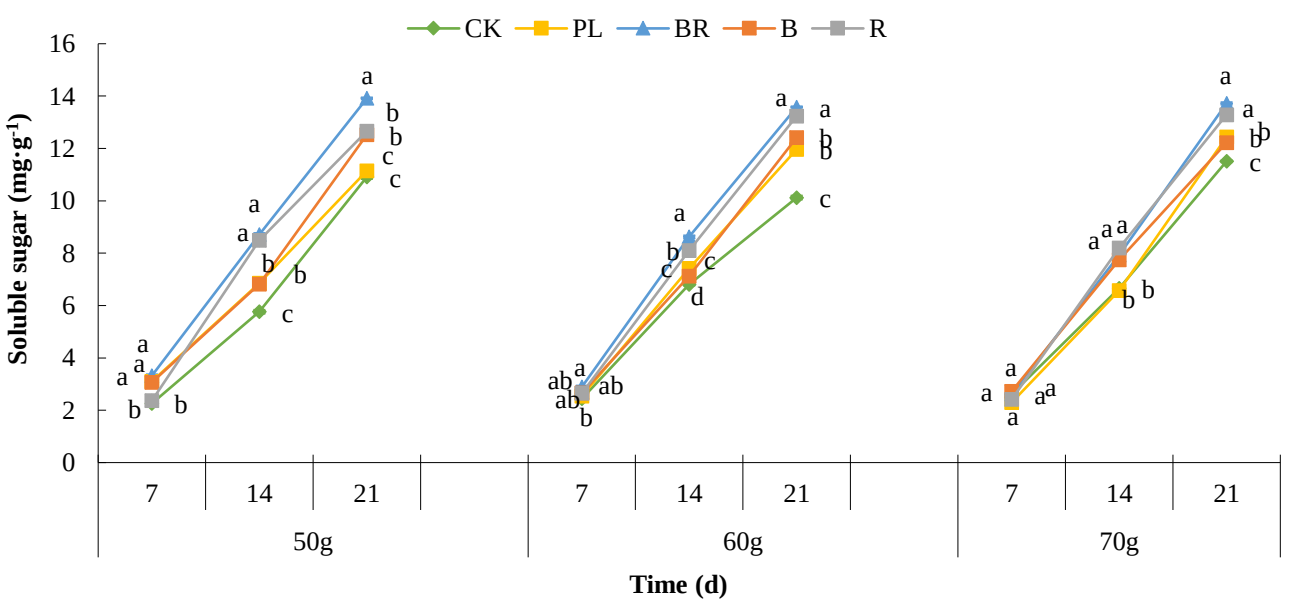

Fig. 2. Changes in soluble sugar in tomato fruits.

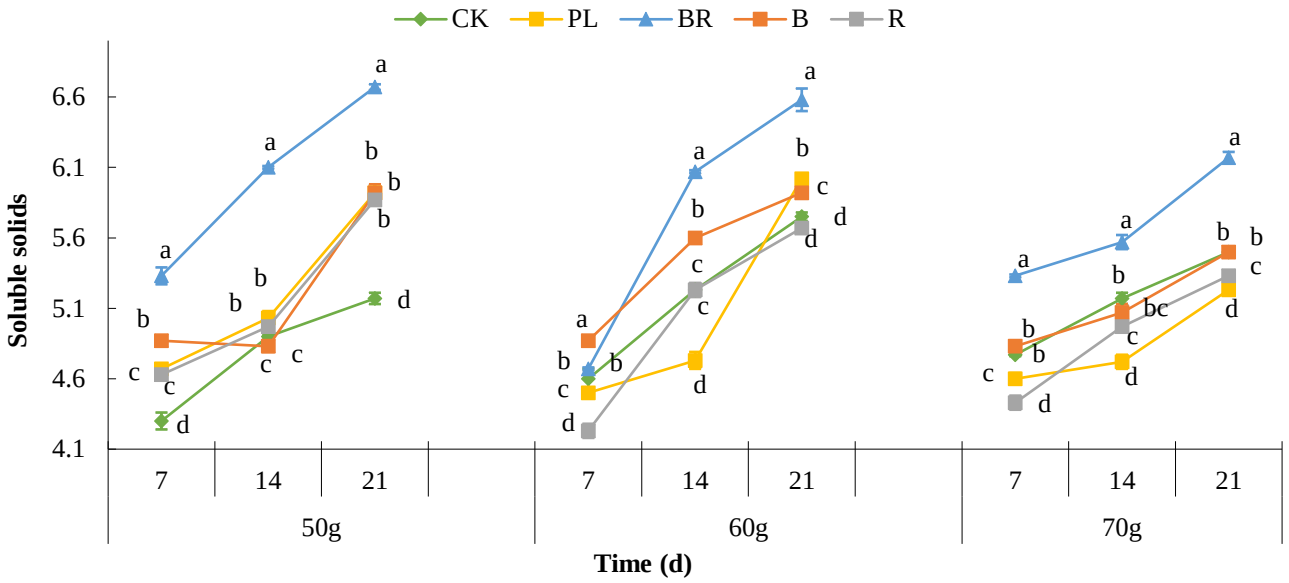

Fig. 3. Change of soluble solid in post-harvest tomato fruits.

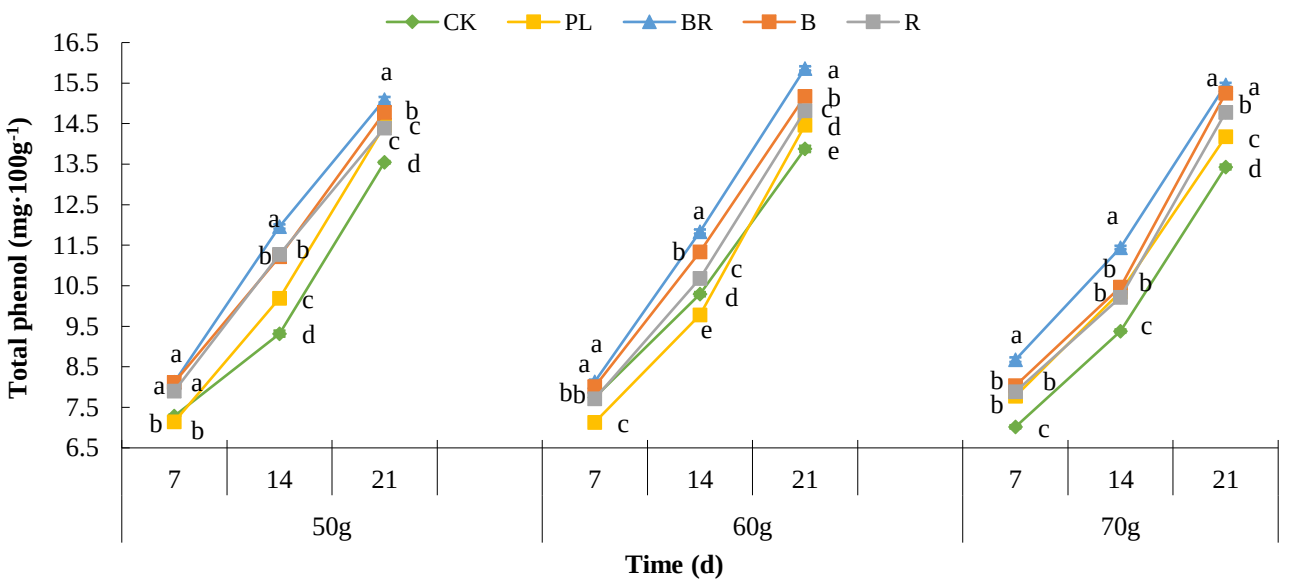

Fig. 4. Change of total phenol in post-harvest tomato fruits.

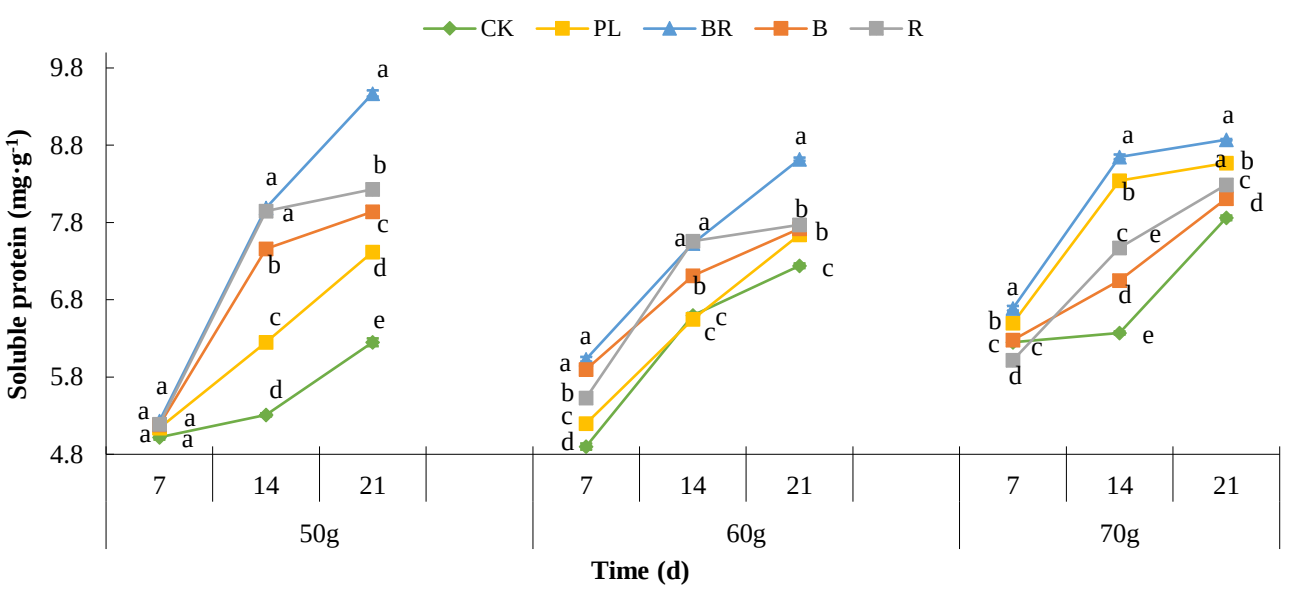

Fig. 5. Changes in soluble protein in tomato fruits.

Discussion

Effects of light quality on lycopene content: The role of light as an environmental factor in regulating the activities of metabolite-related biochemical pathways during the ripening of tomatoes is of significant importance. Furthermore, the influence of light on tomato quality is a crucial factor in determining the quality of the final product (Ntagkas *et al*., 2020). Lycopene, a potent natural antioxidant and the primary carotenoid found in ripe tomatoes, is essential for maintaining human health. It is well established that light is a significant environmental factor influencing the biosynthesis of lycopene. Specifically, red light has been shown to induce increased levels of lycopene content in tomatoes (Xie *et al*., 2019). In post-harvest studies on tomatoes, red light treatment has been shown to increase lycopene of the fruit (Liu *et al*., 2009; Alba *et al*., 2000). In their 2010 study, Liu and colleagues observed that the lycopene content under treatment B was significantly greater than that under other treatments. In a study conducted by Wang *et al*., (2022), it was observed that the application of blue light resulted in a notable increase in the lycopene content of post-harvest tomato fruits. The combination of red (R) and blue (B) supplemental light has been demonstrated to enhance the synthesis of lycopene in tomato fruits (Xie *et al*., 2019). In this study, it was found that BR treatment could increase the lycopene content in tomatoes with different single fruit weights (Fig. 1). The above indicates that light quality can affect the lycopene of tomatoes. Xie *et al*., (2019) revealed that applying supplemented blue plus red light enhanced the expression of essential genes associated with the lycopene synthesis pathway is a crucial process in the production of this essential nutrient. In particular, it was observed that level of expression of light sensing elements, such as the phytochromes (PHYs), which act as red-light receptors, and the blue light receptors known as cryptochromes (CRYs), in addition to the aforementioned light interaction factors, including phytochrome interacting factors (PIFs) and ELONGATED HYPOCOTYL 5 (HY5) either upregulated or downregulated in reaction to blue and red illumination. As a result, the elevated lycopene levels in tomatoes can be linked to the activation of light receptors, which influence the activity of HY5 and PIFs, ultimately regulating the expression of the phytoene synthase 1 (PSY1) gene. However, impact of light quality on different varieties is subject to variation, which may be attributed to species-specific differences in the effects of light quality (Li *et al*., 2010).

Effects of light quality on soluble sugar: The impact of different light qualities on the formation of fruit quality varies (Zhang *et al*., 2021). The sugars present in the fruit of the tomato plant are the primary determinants of the quality and flavors of the tomato, and thus an increase in the concentration of these sugars can enhance the overall quality of the tomato (Zhao *et al*., 2016). Red plus blue light supplementation treatment was observed to promote the expression of genes encoding enzymes involved in the metabolism of sugars in tomato fruits (Dong *et al*., 2019). Liu *et al*. 2010 found that soluble sugar content of tomato fruits was found to be the highest under BR 3:2 treatment. The combination of blue and red light has been demonstrated to markedly enhance the accumulation of soluble sugars in fruit (Samkumar *et al*., 2021). The influence of specific spectral composition of light has been demonstrated to influence the production of biological active compounds in plants is a significant area of study, highlighting that different wavelengths can lead to varied the impact of the aforementioned factors on the phytochemical pathways throughout the plant's life cycle has been elucidated by Nam *et al*., (2018). In this context, recent research has demonstrated that the concentration of soluble sugars is maximized when plants are exposed to red light (Li *et al*., 2024). This phenomenon is particularly evident in upland cotton plantlets and seedlings, where the highest amounts of soluble sugars, including sucrose and starch, were recorded under red light conditions, as noted in previous studies (Li *et al*., 2010; Li *et al*., 2017). Furthermore, Li *et al*., (2023) provided valuable insights into light interactions, revealing that soluble sugar and sucrose concentrations reached their peak when plants were subjected to a light ratio of 1:1, comprising blue and red light, respectively. In contrast, starch content was found to be most elevated under red light in tomato plants. This observation serves to highlight the importance of the lighting quality for plant metabolism. The findings of this study indicate that the soluble sugar content of tomato fruits is higher under BR and R treatments (Fig. 2). Additionally, the study carried out by Zhang *et al*., (2021) highlighted the importance of red light in enhancing the photosynthetic activity of the skin of fruits, which in turn leads to an increase in soluble sugar content. These findings collectively point to the vital role that specific light wavelengths play in optimizing the growth and nutritional quality of plants.

Effects of light quality on soluble solids and total phenol: The application of blue light-emitting diodes (LEDs) has been shown to significantly improve the soluble solids and phenolic content of post-harvest tomato fruit (Wang *et al*., 2022). Compared with white light, RB3:1LED illumination has the effect of increasing the soluble solids content of tomato fruits (Dong *et al*., 2019). The application of white (W), red (R), and blue (B) light-emitting diodes (LEDs) has been demonstrated to enhance the total soluble solids content of tomato fruits. (Palmitessa *et al*., 2021). The application of blue light to post-harvest non-respiratory fruits has been demonstrated to result in a reduction in soluble solids content, whereas the use of red light has been shown to exert an opposing effect (Nassarawa *et al*., 2021). Furthermore, the utilization of reciprocal LED lighting during nocturnal winter periods has been demonstrated to markedly enhance the total soluble solids content of tomato fruits by 20% (Tewolde *et al*., 2016). Liu *et al*., 2010 believed that the content of soluble solids in fruits under treatment B was found to be considerably higher than that observed under alternative treatments. In this study, it was found that the BR treatment significantly increased soluble solids of tomato fruits (Fig. 3), and the BR and B treatments were observed to considerably enhance the total phenol content of tomato fruits (Fig. 4).

Effects of light quality on soluble protein: Most soluble proteins are enzymes involved in various plant metabolic pathways. Accordingly, soluble protein content is regarded as one of the most crucial indicators of plant metabolism on a global scale (Xie *et al*., 2019). The soluble protein content of red okra seedlings was found to be the highest under BR37 lighting conditions (Li *et al*., 2024). Liu *et al*., 2010 discovered that the content of soluble protein in tomato fruits under BR11 was higher than that under other treatments. The findings of this study indicate that the soluble protein content of tomato fruits was higher under BR and R treatments (Fig. 5).

Conclusion

Post-harvest irradiation of tomato fruits utilizing different qualities of light has been shown to produce varying responses in critical quality indicators such as lycopene levels and soluble protein content. Among the different light combinations tested, the pairing of blue plus red light (BR) demonstrated a remarkable enhancement in the concentrations of key nutrients. Specifically, this combination significantly increased the levels of lycopene, soluble proteins, soluble sugars, soluble solids, and total phenolic compounds in the tomatoes, indicating that BR light treatment supports the nutritional enrichment of these fruits. Given these substantial benefits, blue plus red light is recommended as the ideal artificial light source for the light treatment of post-harvest tomatoes. The results from this study offer valuable theoretical insights and practical guidance for selecting optimal light sources for future applications of light irradiation in the post-harvest handling of tomatoes. Additionally, incorporating artificial light treatment into post-harvest processes is a straightforward and effective strategy for physical preservation, which can significantly boost the phytonutrient content in fruits and vegetables after harvest. This not only has substantial implications for enhancing the nutritional quality of these agricultural products but also performs a crucial function in the comprehensive regulation of product quality in the market.

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